ON THE ACCEPTANCE CRITERIA FOR STATISTICAL QUALITY CONTROL IN PAVEMENT CONSTRUCTION

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PRESENTED FOR THE 2002 FEDERAL AVIATION ADMINISTRATION AIRPORT TECHNOLOGY TRANSFER CONFERENCE

05/02

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ABSTRACT

Quality control in pavement construction is associated with steps taken to ensure that the desirable characteristics of a specified property of a product are likely to be achieved. To this end, major agencies around the world utilize the statistical approach. Leading examples of quality-control programs are presented in the construction specifications of the United States FAA (or AASHTO) and of CSIR of South Africa. The latter serves as the basis of the Israeli quality-control program. In-depth study of the U.S. and South African programs reveals considerable deviation between them in the sense that accepted lots with the use of the CSIR program may be totally unacceptable in the FAA program. In addition to these contrasts, this paper discusses the two programs' principal weakness: not creating a satisfactory link between the agency's (consumer's) and the contractor's (producer's) risks. The avoidance of this link leads to opposite trends in increasing or decreasing the size of sample (i.e., the number of observation per any given lot). The paper concludes with operative recommendations for modifying the existing statistical acceptance criteria in order to reduce these limitations.

INTRODUCTION

Quality control in pavement construction is associated with the steps that are taken to ensure that the desirable characteristics of a specified property of a product are likely to be achieved. Quality control also provides a means of assessing the degree of compliance with the standard specifications of the manufactured product. The latter aspect, termed the acceptance judgment, provides a mechanism by which a product can be accepted or rejected relative to prescribed standards. For this purpose, major agencies around the world utilize the statistical approach. Leading examples of quality-control programs are presented in the construction specifications of the United States FAA (or AASHTO) (Reference 1 and 2) and CSIR of South Africa (Reference 3).

In general, statistically based acceptance control has the following advantages: (a) both the quality level and the variability of the product are taken into account in the

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assessment, thus providing greater production flexibility and potentially more economic gain; (b) the need for engineering judgment is reduced, since no such judgment is required to assess the material against the acceptable control limits determined; and (c) the introduction of a conditional acceptance range below the previous coincident acceptance/rejection limit will result in greater procedural flexibility and reduced numbers of disputes in the case of products of marginal quality.

For these reasons, Israeli authorities have been implementing statistically based quality-control programs in their construction specifications over the past several years; it enables them to verify the compliance with the requirements of the degree of compaction obtained. Basically, this program was developed from the South African procedure and adjusted to Israeli conditions. Although the statistical quality-control program was implemented, an in-depth study was conducted to deal with the following topics:

- Comparison of the FAA (or AASHTO) method with the CSIR (South African) method.
- Introducing the agency's risk with the compliance schemes, along with the assigned contractor's risk with quality acceptance, in order to create a satisfactory link between them and to avoid the opposite trends that exist now when increasing or decreasing the size of a sample (i.e., the number of observations per any given lot).
- Elaboration of the known and unknown variability schemes and an evaluation of their outputs.
- Modifications of the Israeli quality-control program in order to reduce some existing limitations.

This paper describes briefly all three methods and presents the main findings obtained from an in-depth study of these topics.

THE SOUTH AFRICAN METHOD

There are no materials and construction processes that are absolutely homogeneous. Therefore, any particular property of a lot can be described by a large number of individual values, which will vary according to some type of distribution. A lot, of course, is a sizable portion of work or quantity of material produced that is assessed as a unit for the purpose of statistical acceptance control. A population with a normal distribution having a mean value, MOP, and a standard deviation, σ, can represent these individual values with sufficient practical accuracy. Since there is no absolute homogeneity, it must be accepted that a limited number of sample test results will yield a mean value, MOS, and a standard deviation, S_N, that may differ from the true population mean value and standard deviation. In addition, it is obviously impractical to test all possible variables that can be drawn from a given population. To complicate matters even further, there is a possibility that the test may belong to a population that is either acceptable or unacceptable in terms of specification (see Figure 1).

The terms ϕ_A and ϕ_U given in Figure 1 are associated with the specification limits, for which three different cases are distinguished: (a) a lower specification limit--in this case, the requirement is that no more than a specified percentage (termed ϕ_A in Figure 1) of the distributed values representing a specified product property should be below a lower specification limit, termed LSL_A in Figure 1; (b) an upper specification limit--the requirement here is that no more than a specified percentage, ϕ_A, should be above an upper specification limit, USL_A; and (c) a double specification limit--no more than a specified percentage, ϕ_A, of the distributed values representing a specified product property should be outside either the lower or the upper specification limits, LSL_A and USL_A. At this juncture, it should be noted that this paper deals mainly with the lower-specification case. The other cases can be treated in the same way.

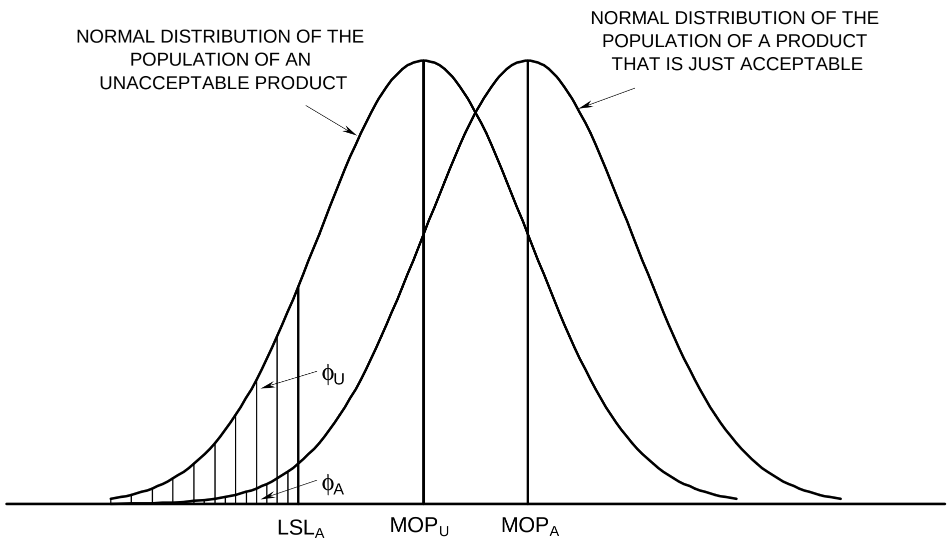

Figure 1: Normal distribution of two populations with a lower specification limit

Note, too, that the term ϕ_A in Figure 1 denotes the percentage of material below LSL_A for a product that is just acceptable. In other words, ϕ_A describes the percentage that is defective (PD) for the lower-limit specification case (Reference 1; see also Figure 4). Its counterpart, 100-ϕ_A, describes the percentage within limits (PWL). Also, the term ϕ_U in Figure 1 denotes the percentage of material below LSL_A for a product that is totally unacceptable (see again Figure 4). Ideally, the percentage of defective material in the tested lot should be zero; however, economic considerations lead to the utilization of a limited value for the percentage that is defective. In Figure 1, this is, $\phi_U>\phi_A\geq 0$.

The population of any given lot can also be represented by mean values of sub-populations, each consisting of a finite number of individual values, N. In this case, the mean of the mean values is still MOP, while the standard deviation is equal to $\sigma/\sqrt{N}$, where σ is (as mentioned earlier) the true standard deviation of the population. This normal distribution of mean values is important, as the mean value of the test results, MOS (mean value of sub-population; i.e., mean value of sample observations), in the control process is used to assess the material. In other words, MOS is compared to the population of the means of both acceptable and unacceptable products. For this comparison, the value of the sample standard deviation, S_N, is used for σ because it is the best available estimated value (see Figure 2).

From Figure 2, the following is evident: if the mean test results (i.e., mean value of sample observations), MOS, are compared to an acceptable limit, LAL, and the product is rejected because MOS is smaller than LAL, the contractor runs the risk of α percent being wrongly rejected. In this case, there is still a α percent probability that the true mean value of the population is equal to MOP_A, which denotes the population mean of a product that is just acceptable in terms of the specification (see Figures 1 and 2). On the other hand, if the product is accepted because the value of MOS is exactly equal to LAL, the agency runs a β percent risk of accepting an unacceptable product. In this case, there is still a β percent probability that the true mean value of the population is equal to MOP_U, which denotes the population mean of a product that is totally unacceptable in terms of the specification (see Figure 1 and Figure 2). Obviously, a perfect acceptance plan would be one in which these two risks, α (the contractor's risk) and β (the agency's risk), were zero. From a practical point of view, this is impossible; consequently, effort is best directed at making these two values as low as possible, while at the same time maintaining practical limits for the quality of the work.

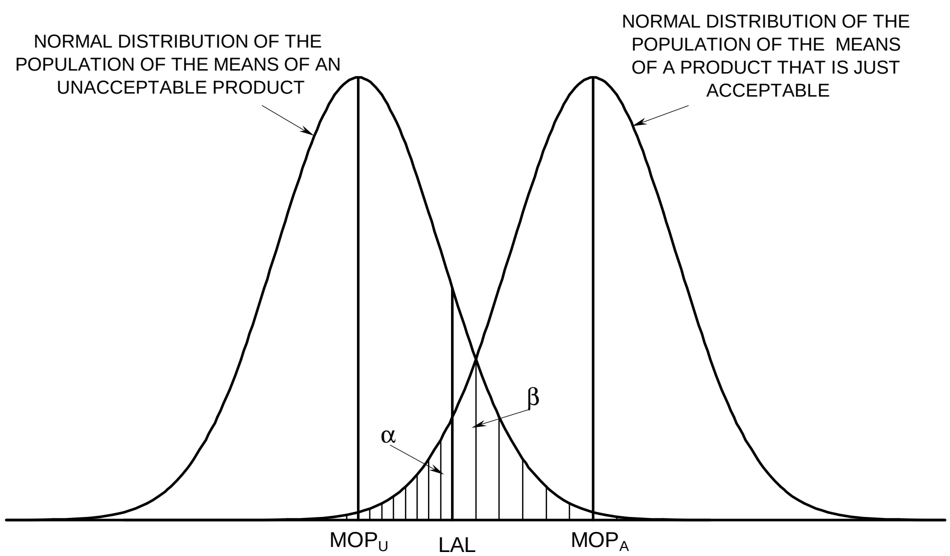

Figure 2: Normal distribution of the two populations of means

It should be added that for a fixed number of observations (i.e., a fixed sample size, N), and a pre-determined α error (i.e., the contractor's risk), the β error (i.e., the agency's risk) is calculated (and not pre-determined as is the already given α error). Furthermore, for a fixed N, a decrease in α error will increase the β error. If there is a wish to decrease both α and β errors, the sample size, N, should be increased. The relationship between these two kinds of risk is dealt with later on in this paper.

The LAL and UAL values (specific for each lot) can be calculated according to the CSIR (South African) method (Reference 3). The relevant expressions for these calculations are described below.

It is evident from Figure 1 that the following expression exists for the lower-specification limit:

$$MOP_A=LSL_A+k_\phi\times S_N \qquad (1)$$

In the same manner, the following expression exists for the upper-specification limit:

$$MOP_A=USL_A-k_\phi\times S_N \qquad (2)$$

In these two equations, k_ϕ is the constant for a normal distribution related to ϕ_A, the value of which may be obtained from the standard table for normal distribution. Usually, ϕ_A is equal to 10%; thus, k_ϕ =1.282.

From Figure 2, it is evident that the following expression exists for the lower specification limit:

$$LAL=MOP_A-k_\alpha\times S_N/\sqrt{N} \qquad (3)$$

It can be shown from Equation 1 that Equation 3 can be transformed into the following form:

$$LAL=LSL_A+k_A\times S_N \qquad (4)$$

where:

$$k_A=k_\phi-k_\alpha/\sqrt{N} \qquad (5)$$

In the same manner, the UAL value is calculated from the following expression for the upper-specification limit:

$$UAL= LSL_A-k_A\times S_N \qquad (6)$$

In Equation 5, k_α is the constant for a normal distribution related to α, the value of which may be obtained from the standard table for normal distributions. Usually, α is equal to 5%; thus, k_α =1.645. Finally, the calculated k_A values for α=5% and ϕ_A=10% are given in Table 1.

Table 1: k_A values for α=5% and ϕ_A=10%

Sample Size, N	3	4	5	6	7	8	9
k_A	0.332	0.459	0.546	0.610	0.660	0.700	0.734

When the mean value of the sample observations in a given lot, MOS, is compared to LAL and UAL, the lot is accepted when:

$$MOS \geq LAL \quad (7)$$

$$MOS \leq UAL \quad (8)$$

In addition to LAL and UAL, the limiting rejection limits, LRL and URL, should also be calculated. As the South African procedure for determining these limits was not adopted for the Israeli method, a detailed description is omitted here. Also, to conclude, it is worthwhile emphasizing that the South African procedure does not take in a direct manner the agency's risk considerations. This is done later on in this paper.

EFFECT OF SAMPLE SIZE

The standard deviation multiplier, known as the acceptance constant k_A of Equation 5, is a function of the proportion defective (PD=ϕ_A), the assigned probability of acceptance (100-α, where α is the contractor's risk), and the sample size (N). This is illustrated in Figure 3 for a percentage of10% defects.

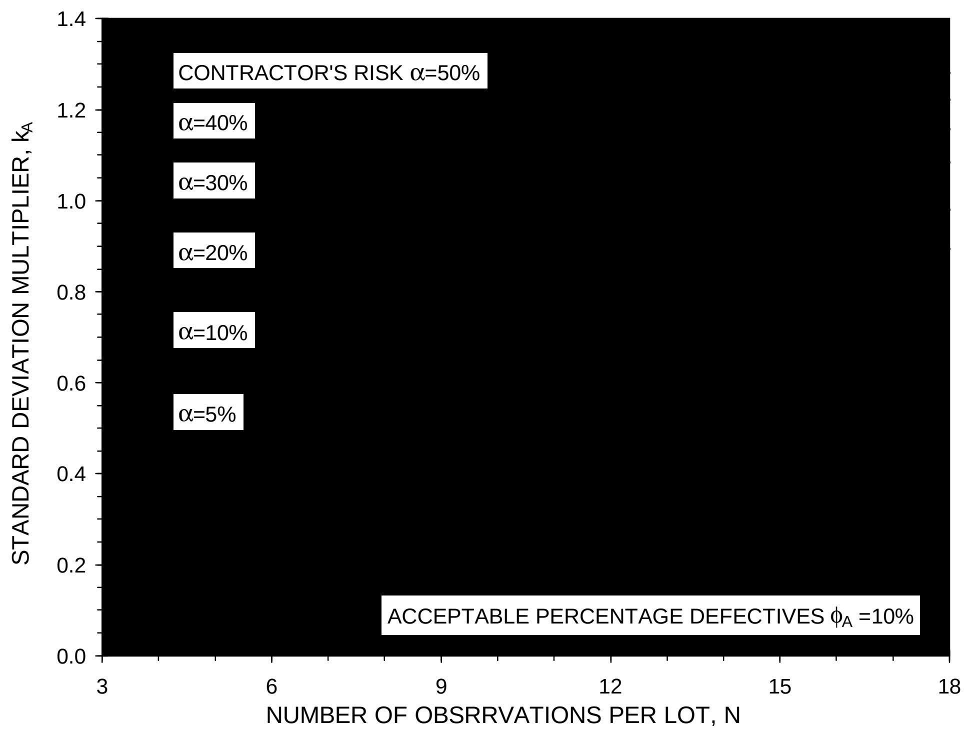

Figure 3: Standard deviation multiplier as a function of sample size for various values of contractor's risk and acceptable percentage of defects

Figure 3 reveals an important phenomenon, expressed as the increase of the standard deviation multiplier with the increase of sample size along a given contractor's risk line. This phenomenon means that a lot that is just acceptable for a given number of observations becomes unacceptable when the same values of the mean of observations and their standard deviation are also obtained from an increased number of observations of the same lot. Accepting this type of control scheme means that the contractor may lose from increasing the number of observations per lot; at the same time, the agency may win from this increase. Thus, a balance should be established between these two trends.

In order to establish this balance, the agency's risk concept should be taken into consideration. This involves defining a <u>bad</u> together with a <u>good</u> product as shown in Figure 4 (see also Figure 1). The quality can be designated as low, medium, or high, where products of high and medium quality are acceptable, while products of low quality are unacceptable. From this point of view, the α value, or the contractor's risk, is the probability of the wrong rejection of a product whose quality is exactly on the borderline between medium and high (the GOOD mark). Similarly, the β value, or the agency's risk, is the probability of the wrong acceptance of a product whose quality is exactly between low and medium (the BAD mark).

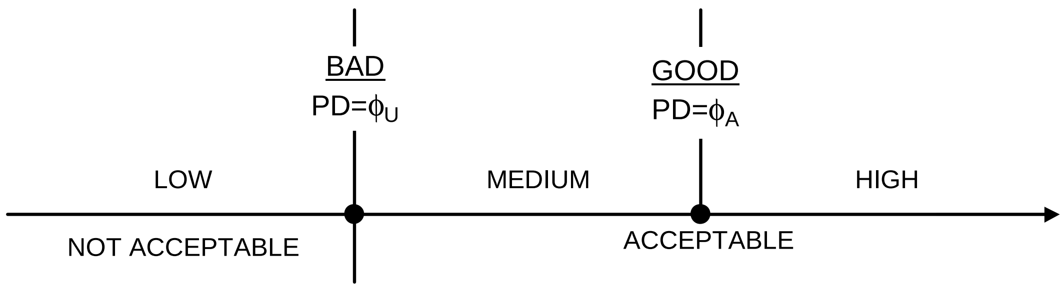

Figure 4: Quality levels of a product (Note: ϕ_A and ϕ_U are described in Figure 10

The above control scheme is given in Figure 5 for (a) a starting point defined by ϕ_A=10%, α=5%; and (b) three plans for a sample size per lot. The curves of this figure are called the operating characteristics (OC curves). They show again that the sample size affects the <u>agency's</u> risk for any given value of ϕ_A; the higher the sample size, the lower is this risk for any given starting point. The implications of this phenomenon are dealt with in the next section.

Note, that Figure 5 includes also an additional OC curve for N=6 as constructed for an unknown variability scheme. This has been done for further reference in this paper.

AGENCY'S RISK CONSIDERATIONS

When the agency's risk is also implemented in the compliance criteria, a bad product-- as shown in Figure 4-- should be defined as having a greater percentage of defects than a specified value of ϕ_U (See Figures 1 and 4). Three such specified values of ϕ_U are defined in Figure 6 for calculating the variation in the standard deviation multiplier (i.e., the acceptance constant, k_A) with the increase in the number of observations per lot. These specified values are 20%, 30%, and 40%. It can be shown from Figure 5 that when a pre-defined starting point of ϕ_A=10% and α=5% is applied, each of the above values of ϕ_U possesses a fixed value of the agency's risk (the β value). These

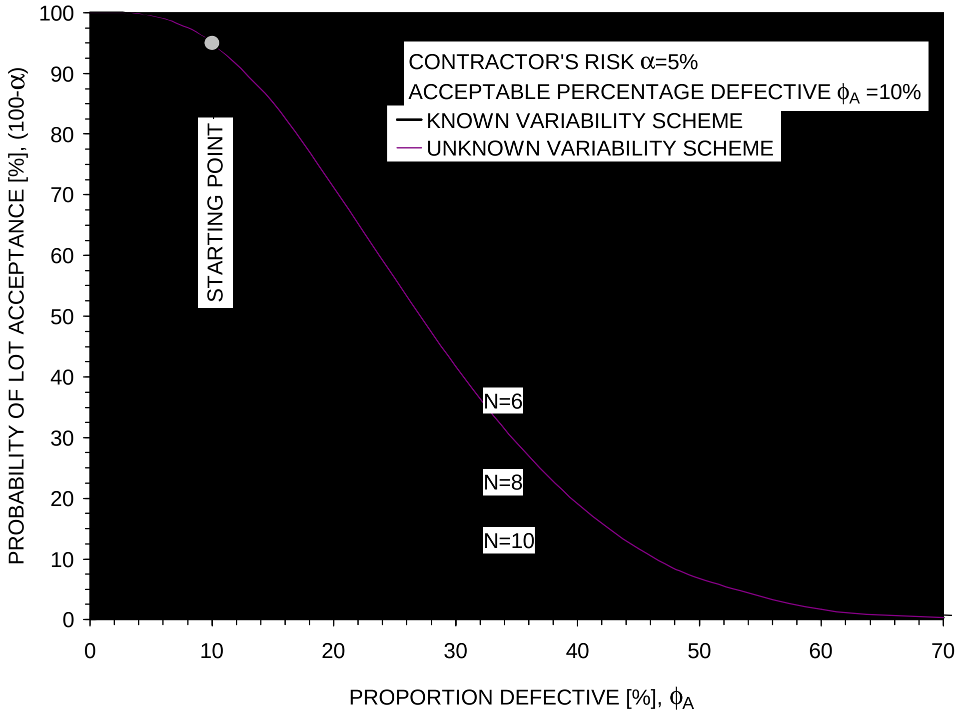

Figure 5: Operating characteristics for known and unknown variability schemes

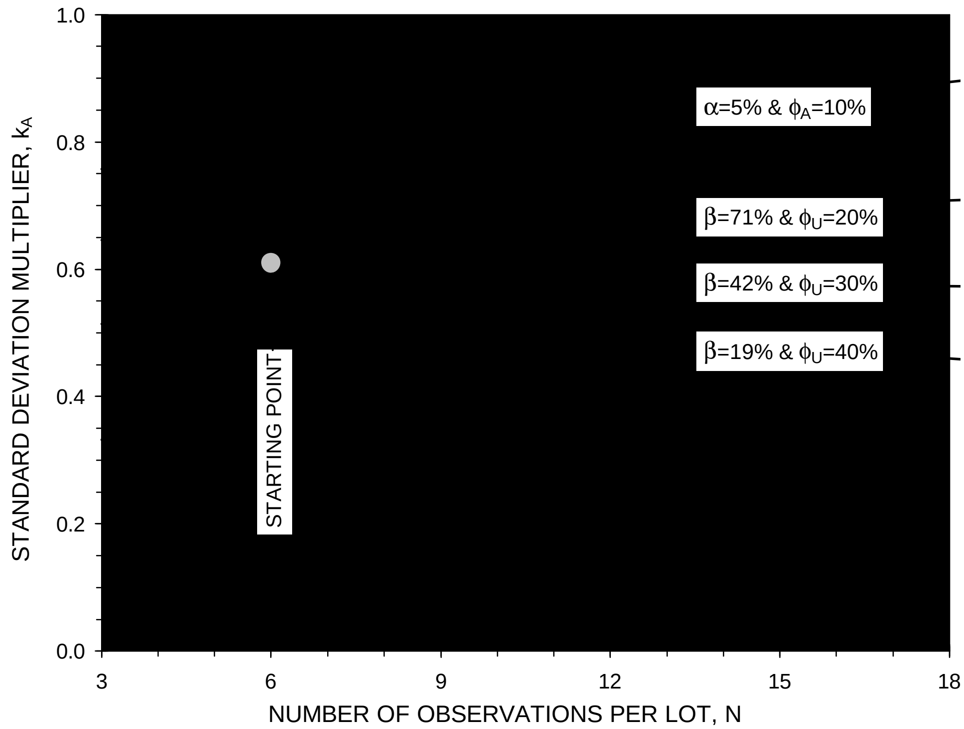

Figure 6: k_A as a function of sample size for different cases of acceptance parameters

Now, if a scheme of six observations per lot is dictated in the specification, it seems reasonable that the contractor's risk will be reduced when, for any given reason, a higher number of observations per lot are utilized. Obviously, the reduction should be in a way that will keep the agency's risk at the same level to maintain fairness with respect to this risk (see Figure 7). Thus, the question that arises from Figure 6 is, what curve of the pair values of agency's risk and unacceptable (rejected) percentage of defects should be followed? For a good balance, the use is suggested of a horizontal curve of a constant k_A value, which lies very close to the ϕ_U=30% and β=42% curve. For this curve, k_A is equal to 0.610, and it is suggested that this be applied for any given number of observations per lot, even less than 6.

To repeat, it is suggested that all the k_A values of Table 1 be replaced by one constant value of 0.610. Obviously, the new contractor's risk obtained from this constant value becomes a function of the number of observations, as displayed in Table 2.

Table 2 indicates that for a lower number of observations than 6 per lot, more than 5 of 100 tested lots of good product, as defied in Figure 4, will be wrongly rejected. It seems that this increase in the contractor's risk is justified in order to maintain an appropriate agency's risk level for a reduced number of observations per lot.

Table 2: Contractor's risk for ϕ_A=10% and a constant k_A value of 0.610 (α=5% and N=5)

Sample Size, N	3	4	5	6	7	8	9
Contractor's Risk, α [%]	12.2	8.9	6.6	5.0	3.8	2.9	2.2

EFFECT OF UNKNOWN VARIATION

As mentioned earlier, all the former relevant derivations are made on the basis that the value of the sample standard deviation, S_N, can be used as the population standard deviation, σ, because it is the best available estimation for the latter parameter. This acceptance scheme is denoted the known variability scheme.

When the product variability is not known or does not need to be controlled and the specifications require assurance regarding a maximum defective proportion to a maximum defective proportion for a designated control value, a lot-by-lot compliance scheme can be based on the same basic equations as the known variation scheme; namely, Equations 4, 6, 7, and 8. Here it should be emphasized that for the present scheme, Equation 5 is not valid. Instead, appropriate statistical tables are available to supply the new required k_A values (see Reference 4), which constitute the acceptance constant with a non-central-function t- distribution. Again, the new k_A value is a function of the sample size N, the proportion that is defective, and the assigned probability of acceptance. The derivation of this non-central t-statistic, k_A, is discussed in Reference 5.

Figure 5 displays the OC curve for the unknown variability scheme for testing a lot with 6 observations when the contractor's risk is 5% and the acceptable percentage of defects is 10%. Accompanying this curve is another OC curve, but constructed this time for the known variability scheme with the same acceptance parameters. The figure indicates that the OC curve for the known variability scheme has a more discriminating power between good and bad product qualities. That is, although the two schemes use a sample size, N, of 6 tests, the use of a known variability scheme will result, relative to the unknown variability scheme, in a greater reduction in the probability of lot acceptance for a product with a given defection proportion that is in excess of the required maximum of 10 per cent.

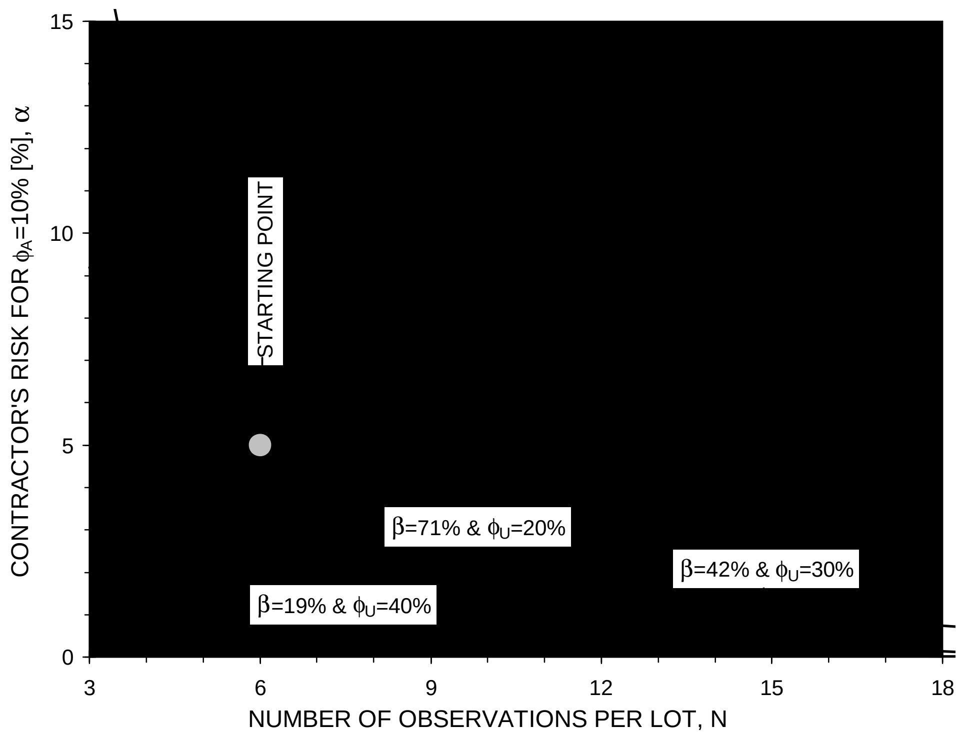

Figure 7: α as a function of sample size for the acceptance parameters of Figure 6

Table 3: k_A values for the unknown variation scheme, where α=5% and ϕ_A=10%, and the corresponding α values for the known variation scheme

Sample Size, N	3	4	5	6	7	8	9
k_A	0.335	0.444	0.519	0.575	0.619	0.655	0.686
Corresponding α [%]	5.0	4.7	4.4	4.2	4.0	3.8	3.7

Table 3 also shows the standard deviation multiplier values, k_A, for the unknown variation scheme, where α=5% and ϕ_A=10%. These values are generally smaller than the corresponding ones of Table 1. This is also learned from the α values calculated for the known variation scheme, where ϕ_A remains equal to10% and k_A values are equal to those given in Table 3. Obviously, these corresponding new α values are smaller than 5% as shown in Table 3.

Still another set of approximate equations for calculating the k_A and β values for the unknown variability scheme, where the values of α, ϕ_A, ϕ_U, and N are pre-fixed, is given by Wallis (References 8 and 9). These approximate equations are as follows:

$$k_A=[(k_\alpha \times k_{\phi A}+k_\beta \times k_{\phi U})/(k_\alpha+k_\beta)] \quad (9)$$

$$N=[(k_A^{2}+2)/2]\times[(k_\alpha+k_\beta)/(k_{\phi A}-k_{\phi U})]^2 \quad (10)$$

These two equations are solved by the trial-error method. For α=5%, ϕ_A=10%, ϕ_U=30%, and N=6, the values obtained for k_A and β are 0.560 and 46.8%, respectively. Comparing this result with the values given in Table 5 (k_A=0.575) and Figure 5 (β=48.1%) leads to the conclusion that the two calculation methods lead to similar results.

FAA OR AASHTO METHOD

The FAA or AASHTO framework for acceptance plans is based on principles formulated in U.S. Military Standard 414. This standard was prepared in order to meet a growing need for the use of standard inspection sampling plans by variables in Government procurement, supply and storage, and maintenance-inspection operations.

According to FAA (Reference 1) or AASHTO (Reference 2), the percentage within limits (PWL) serves as the governing parameter in the acceptance plan. This method accounts for both the average level and the variability of the construction process in a statistically efficient way. It is considered advantageous for the following reasons: (a) it is relatively easy to understand and apply; (b) it is readily applicable to most construction-quality characteristics; and (c) it promotes uniform quality within specified limits believed to be associated with ultimate performance.

The rationale behind this method assumes that the test data for a monitored characteristic follow a pattern of normal distribution. Based on this rationale, the arithmetic mean (MOS) and standard deviation (S_N) were computed and used to determine what is termed a lower-quality index (Q_L) and an upper-quality index (Q_U):

$$Q_L=(MOS-LSL_A)/S_N \quad (11)$$

$$Q_U=(USL_A-MOS)/S_N \quad (12)$$

The Q_L value serves to estimate the PWL_L value, defined as the percentage that falls above the lower specification limit (LSL_A). This is done by referring to FAA or AASHTO statistical tables for the variability-unknown procedure. Figure 8 has been constructed and the values of Q_L corresponding to PWL_L=90% have been extracted from this procedure and are displayed in Table 4.

Table 4: FAA or AASHTO Q_L Values for PWL_L=90%

Sample Size, N	3	4	5	6	7	8	9
FAA or AASHTO, Q_L	1.096	1.200	1.229	1.242	1.249	1.254	1.257

In the same manner, the Q_U value serves to estimate the PWL_U value, defined as the percentage that falls below the upper specification limit (USL_A). Again, this is done by referring to FAA or AASHTO statistical tables. For negative values of Q_U (and Q_L), the values derived from these tables should be subtracted from100.

Note that if LSL_A is not specified, PWL_L will be 100; if USL_A is not specified, PWL_U will be 100. Finally, PWL is calculated according to the following expression:

$$PWL=(PWL_L+PWL_U)-100 \tag{13}$$

It can be seen from the above discussions that the development of the FAA or AASHTO method does not include the contractor's risk parameter. That is to say, for this method, k_α=0, which means that the contractor's risk is 50%. The same can be derived from Table 5. This table displays the results of two calculations: (a) the first leads toward calculated values of percentage defects, ϕ_A, according to the South African known variability method for a pre-determined contractor's risk, α, of 5%; (b) the second leads toward calculated values of contractor's risk, α, according to the same method for a pre-determined acceptable percentage of defects, ϕ_A, of 10%. Both calculations make use of the FAA or AASHTO acceptance values (marginal values) for the case of lower specification limit only where PWL=90%.

The extreme discrepancy that exists between the South African pre-determined ϕ_A value for α=5% (i.e., ϕ_A=10%) and the values given in the middle row of Table 5 may make a lot that is rejected when using the FAA or AASHTO method fully acceptable when using the South African method. In addition, such a high producer's risk of lot rejection, of about 50%, associated with the FAA or AASHTO method, would normally render the specification economically unworkable. The only possible way to overcome this discrepancy is to assign a lower requirement for the FAA or AASHTO method.

Table 5: South African ϕ_A and α values for FAA or AASHTO marginal values

Sample Size, N	3	4	5	6	7	8	9
ϕ_A [%] for α=5%	2.0	2.2	2.5	2.8	3.1	3.3	3.6
α [%] for ϕ_A=10%	37.5	43.5	45.3	46.1	46.5	46.8	47.0

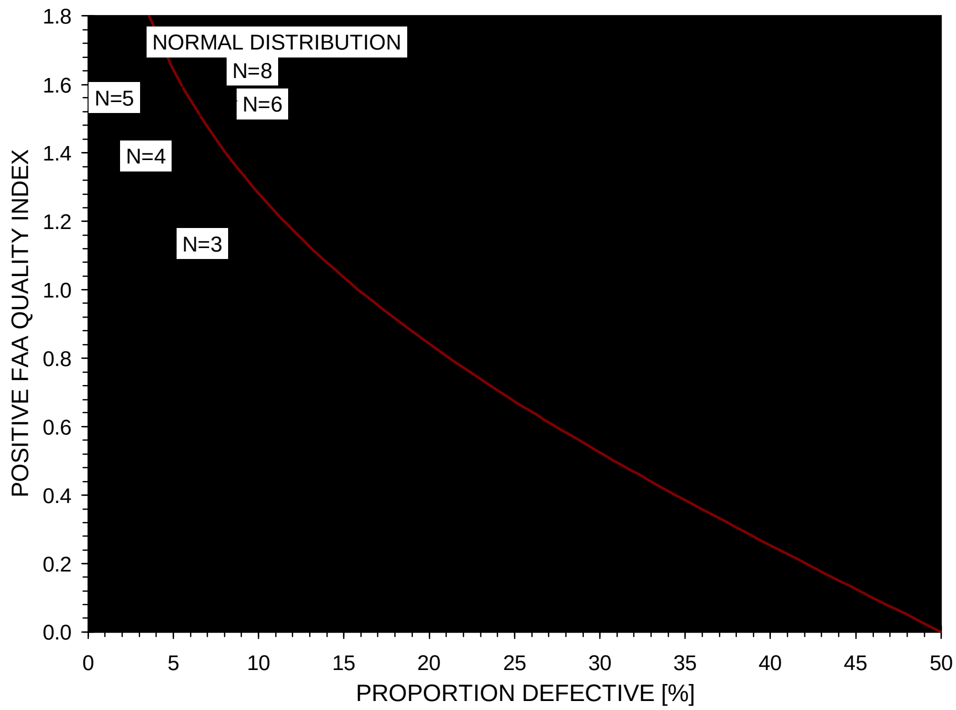

Figure 8: Positive FAA quality index versus percentage of defective products for different sample sizes

To conclude, the above comparison demonstrates the fact that in order to switch from the South African to the AASHTO method without greatly changing the acceptance policy, the quality index equations (Equations 11 and 12) should be modified in the following way (see also Equations 1 and 2):

$$QL=(MOS-LSL_A+1.645\times S_N/\sqrt{N})/S_N \qquad (14)$$

$$QU=(USL_A+1.645\times S_N/\sqrt{N}-MOS)/S_N \qquad (15)$$

Thus for N=6 and a South African LSLA of 97.0%, the comparable FAA or AASHTO LSL_A should be 96.3% when S_N equals 1.0%. Indeed, this requirement is specified in the FAA specification (Reference 1) for the compacted asphalt density percentage.

THE ISRAELI METHOD

In Israel, as in other countries, the decision to utilize statistically oriented acceptance-control procedures did not originally meet with enthusiasm from the road engineering community. Moreover, the fact that the LAL value is always higher than the LSL_A value for non-zero S_N values (see Equation 4) made this community feel that the South African quality-control procedure was more stringent than the old conventional method. Thus, it was found necessary to relax the South African procedure somewhat in order to allow the construction industry to adjust.

Figure 9 introduces the Δ parameter in order to relax the specification requirements. The modified LAL and UAL values are as follows:

$$LAL=LSL_A-\Delta+k_A \times S_N \quad (16)$$

$$UAL=USL_A+\Delta-k_A \times S_N \quad (17)$$

In the Israeli specifications, the value of Δ is equal to 0.5%. It can be shown that this value approximately doubles the value of ϕ_A for S_N=1.0% if LAL and UAL are calculated directly from the given LSL_A value with the appropriate modified k_A values (see Table 6).

When LAL=LSL_A and UAL=USL_A are defined as pre-determined equalities, the corresponding ϕ_A of these calculations for two values of Δ, 0% and 0.5%, are as presented in Table 3. The middle row of the table indicates that for the Δ=0% case, the above pre-determined equalities dictate much higher percentage defect (ϕ_A) values than the accepted 10% (see also Table 6). In contrast, the closing row of Table 7 indicates that for the Δ=0.5% case, the pre-determined equalities dictate percentage defect values that are similar to the accepted 10%. Thus, the use of these equalities in the Δ=0.5% case may be regarded as acceptable, but only when S_N is around 1.0%.

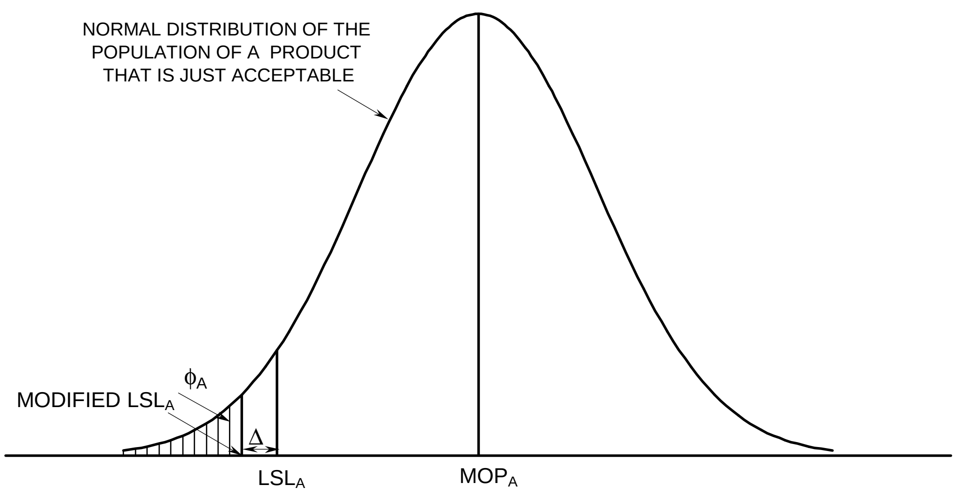

Figure 9: Normal distribution of an acceptable population with a lower specification limit

Table 6: South African ϕ_A values for marginal values of the Δ=0.5% case

S_N (%)	0.1	0.5	1.0	1.5	2.0	2.5	3.0
South African ϕ_A	$100\times[1\text{-Normsdist}(1.282-0.5/S_N)]$						
	100.0	38.9	21.7	17.1	15.1	14.0	13.2

Note, that the definition of the Normsdist function written in Tables 6 and 7, is according to that given in the MS Excel software (see Reference 6). Finally, it should be noted that the full details about the Israeli method are to be found elsewhere (see Reference 7).

Table 7: South African ϕ_A values for α=5% when LAL=LSL_A and UAL=USL_A

Sample Size, N	4	5	6	7	8
South African ϕ_A for Δ=0%	$100\times$[1-Normsdist(1.645/$\sqrt{N}$)]				
	20.5	23.1	25.1	26.7	28.0
South African ϕ_A for Δ=0.5% & S_N=1.0%	$100\times$[1-Normsdist(1.645/$\sqrt{N}$+0.5)]				
	9.3	10.8	12.1	13.1	14.0

SUMMARY AND CONCLUSIONS

Quality control in pavement construction is associated with steps taken to ensure that the desirable characteristics of a specified property of a product are likely to be achieved. These steps also provide a means of assessing the degree of compliance with standard specifications of the manufactured product. The latter aspect, termed the acceptance judgment, provides a mechanism by which a product can be accepted or rejected relative to prescribed standards. Toward this end, major agencies around the world utilize the statistical approach. Leading examples of quality-control programs are presented in the construction specifications of the United States FAA (or AASHTO) and the South African CSIR. The latter serves as the basis of the Israeli quality-control program.

In-depth study of these two programs reveals a considerable deviation between them in the sense that accepted lots with use of the CSIR statistical program can be totally unacceptable in the FAA program. This paper also discussed the two programs' principal weakness in not creating a satisfactory link between the agency's (consumer's) and the contractor's (producer's) risks. The absence of this link leads to opposite trends in increasing or decreasing the size of the sample (i.e., the number of observation per any given lot).

Thus, the findings and the conclusions of this paper are these:

- For a scheme of six observations per lot, a constant k_A value is suggested for use with the South African (or the Israeli) method even when a higher number of observations per lot is utilized, thus reducing the contractor's risk and keeping the agency's risk at the same level.
- For the South African (or the Israeli) method, the known variability scheme is more stringent than the unknown variability scheme; thus the first scheme is preferable.

- There is considerable deviation between the FAA or AASHTO and the Israeli methods in the sense that accepted lots with use of the Israeli method can be totally unacceptable with the FAA or AASHTO method.
- Calculations demonstrate that in order to switch from the Israeli method to the FAA or AASHTO method without greatly changing the acceptance policy, the quality index equations should be modified.

Finally, implementation of these conclusions in the Israeli method is highly recommended. Again, when the FAA or AASHTO method is to be used, the current Israeli specification requirement for the LSL_A value should be reduced.

ACKNOWLEDGMENTS

This paper was written as a result of fruitful discussions with Eng. Eran Freund on the subject matter. The paper was prepared with the assistance of Mr. Arieh Aines, graphics editor. Thanks are therefore due both of them.

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